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Seismic Performance Evaluation of a Multi Storey RC Structure Subjected to Strong Ground Motions

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Abstract: A tremor or a movement of the ground occurs during an earthquake on Earth's surface. Earthquakes can also cause landslides and volcanic eruptions. Natural disasters or human activity can produce earthquakes, which are defined as seismic events generating seismic waves. Earthquakes most commonly occur when geological faults rupture, however they can also occur as a result of volcanic eruptions, landslides, mine explosions, and nuclear testing. The study of structural behavior towards different ground motions is therefore one of the main criteria to determine damage intensity. Structural Analysis of a residential building is carried out by using ETabs Software. Present study is intended to study the dynamic behavior of Multistorey Reinforced Concrete structure by considering, an existing G+13 storey residential building is modeled and its structural behaviour is studied using Time history method by considering different high intensity earthquakes. The behaviour of the building is studied mainly for its base shear, Storey displacement and maximum joint displacement.
Keywords: Earthquake, ground motions, ETABS Software, Multistorey Reinforced Concrete structure, Base shear.

I. INTRODUCTION

The term urbanisation refers to the process of people relocating to cities from other locations. As more people move to metropolitan centres, the need for housing and workplaces grows. It is advantageous to locate major structures with many users near the city centre or public transportation hubs. A solution is to design and construct higher structures to utilise the space above ground, increasing the capacity of the same ground area as lower buildings [1]. However, as structural height increases, the horizontal loads such as wind and seismic loads, also increases, as well as the effect of severe damage or collapse. Several big earthquakes have occurred, causing significant devastation in terms of both human lives and economic costs. An earthquake that hit Kobe, Japan, in 1995 resulted in over 5000 deaths, over 30.000 seriously injured people, and over 300.000 people losing their homes. Other severe catastrophes included the earthquakes in Loma Prieta in 1989 and Northridge in 1994, which resulted in damage expenditures of more than US$ 50 billion [2]. An earthquake is caused by the fast release of strain energy trapped in the earth's crust, which produces seismic waves. Structures are sensitive to earthquake ground motion, which causes structural damage. Figure 1 shows the severe damage for buildings during Bhuj earthquake (2001). It is critical to understand the features of ground motion in order to protect structures from damage caused by it. Peak ground acceleration (PGA), frequency content, and duration are the most essential dynamic aspects of an earthquake. These properties are important in researching the behaviour of structures subjected to earthquake ground motion [3]. The response spectrum approach or time-history method can be used to do linear dynamic analysis. The response spectrum method is easy to understand because the seismic forces are directly related to the design spectrum and mode periods. However, acceleration time histories or accelerograms are required for the time-history analysis. These accelerograms must be compatible with the design spectrum, according to the standards. An accelerogram is said to be compatible with a specific design spectrum if its 5% damped response spectrum is close to the design spectrum within a specified period range, often known as the period range of interest [4]. The effect of local soil conditions and tall building safety evaluation are required for earthquake resistant design. Linear dynamic structural analysis with soil-structure interaction (SSI) is required. When a building built on rock experiences ground motion, the extraordinarily high stiffness of the rock limits the rock motion. The structure can be assumed to have a fixed base, and the reaction is accurate. If the same structure was supported on soft soil, it would react differently. When the supporting medium, i.e., soil, is regarded an intrinsic element of the structure, the dynamic characteristics of the structure alter. This is represented in a major change in the structure's response in storey drift, stress components, and so on when compared to that of the structure on rigid foundation.

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Fig.1 Severe damage on buildings during Bhuj Earthquake (2001)

II. METHODOLOGY

A. Description of the Building

A G+13 Storey R.C. building, a real time structure which is under construction near Chennai is considered for the present study to investigate SSI effects on tall buildings. The plan dimension of the building is 28.20 m x 16.10 m and the height of the building is 40.15 m from the ground level.

The structure is symmetrical and the floor dimension details at different portions are tabulated in Table I. Elevation and storey details are shown in Table IIIII. The stilt and first storey height are 4 m and 3.15 m respectively from the base level and all other stories are 3 m and replicas of the first storey.

TABLE IV: GRID Dimensions

Floor	Height
Basement Floor below Tower	4.00 m
Basement Floor beyond Tower	3.75 m
Stilt Floor	4.00 m
Typical Floor	3.00 m

TABLE VVI: Height and Elevation of Stories

Level	Height (in m)	Elevation (in m)	Similar to
Terrace	3.00	40.15	
Storey 11	3.00	37.15	
Storey 10	3.00	34.15	
Storey 09	3.00	31.15	
Storey 08	3.00	28.15	
Storey 07	3.00	25.15	Storey 1
Storey 06	3.00	22.15	
Storey 05	3.00	19.15	
Storey 04	3.00	16.15	
Storey 03	3.00	13.15	
Storey 02	3.00	10.15	
Storey 01	3.15	7.15	Master Storey
Stilt floor	4.00	4.00	
Base	0	0	

As this is a multi-storey structure of G+13 stories all utilities and parking facility to be made inside the building. The basement and stilt floors are meant for parking. The utility structures such as domestic and fire underground sump and pump house, sewage treatment plants have been planned in the basement floor. The purpose is explained to clarify the need of the stilt floor. The layout of the base plan dimensions and the positions of shear walls and columns are shown in the Fig. 6.2. The construction is an ordinary beam, slab, column and shears wall construction with conventional shuttering and form works. In present study the wind load has been neglected to reduce the complexity and to concentrate more on seismic response.

B. Grades of materials used in modelling

Materials used in the design and construction of the building were employed in the model, and their grades are shown in Table VIIVIIIIX according to IS 456-2000. Name of the material, mass per unit volume, weight per unit volume, modulus of elasticity, and Poissons ratio should be indicated for each type of material defined while modelling in the property data section..

TABLE XXIXII: Grades of materials used in modelling

Structural Member	Grade of Materials
Slabs	M25
Beams	M25
Columns	M40
Retaining walls	M25
Reinforcement Steel	Fe 500 for all elements except floor slabs
Floor slabs	Fe 415

C. Seismic Loads used in Modelling

The parameter that has been taken in the seismic analysis of the tall building in the present study as per IS1893-2016 (Part I) are shown in table XIIIV. No more than 3 levels of headings should be used.

TABLE XIVV: Soil type and Seismic details

Soil Type	Soft soil (Local Site Condition)
Response Reduction Factor	5
Zone Factor	0.16
Importance Factor	1.2
Damping	5%

D. Column Sizes used in Modelling

Different columns sections used in modeling are shown in Table V below. All columns are made of M40 grade concrete and of Fe 500 grade steel.

TABLE V: Details of Columns

Column Sizes	Grade of Materials	Grade of Steel
300 mm × 900 mm	M40	Fe 500
300 mm × 2750 mm		
200 mm × 1250 mm × 1800 mm		
300 mm × 1800 mm		
900 mm × 300 mm		
300 mm × 1200 mm		
300 mm × 1200 mm		
300 mm × 2700 mm		
200 mm × 450 mm × 1800 mm		

R.C Shell elements are used to model slabs and shear walls. The shell element is a stack of single-layer membranes of varying thickness and eccentricity. Shell elements can have quadrilateral or triangular geometrical shapes. Because the floor slabs are believed to be rigid diaphragms, they are modelled using membrane elements. 3-D Shell parts are used to model the Shear walls. Table VI shows the designation, thickness, and material grade for Slabs and Walls as shell sections.

TABLE VI: Shell Element types and Thickness

Slab and Wall	Design Type	Element Type	Material	Thickness (mm)
S115	Slab	Membrane	M25	115
S125	Slab	Shell-Thin		125
S125S	Slab	Shell-Thin		125
S150	Slab	Membrane		150
S150S	Slab	Shell-Thin		150
Stair	Slab	Membrane		225
W200	Slab	Shell		200
W250	Slab	Shell		250
W300	Slab	Shell		300

E. Load Combinations Considered for the Present Study

Safety and serviceability are two critical considerations in the design and construction of any tall structure. The limit state design method incorporates safety and serviceability factors into the design of structures. The limit state of collapse of a structural element is the crucial state in which ultimate or yield stress values are attained. The serviceability standards in seismic response of tall buildings are restricting the inter-storey drift levels.

The following load combinations shall be accounted for as per IS 1893 (Part 1): 2016

1) 1.5(DL+LL)
2) 1.2(DL+LL±EL)
3) 1.5(DL ± EL)
4) 0.9(DL±1.5EL)

Where, DL- Dead load, LL- Live load and EL- Earthquake load

When earthquake forces are added to other normal forces, the permitted stresses in the material can be increased by 33% in the elastic method of design. When earthquake pressures are included, the allowable bearing pressure in soils must be adjusted in accordance with Table 1 of IS 1893 (part 1):2016, depending on the kind of foundation. Table VII shows the various load combinations to be considered for the analysis, design, and investigations in accordance with IS 1893 (part 1):2016.

TABLE VII: Shell Element types and Thickness

Sl. No.	Load Combination	Load Factors		
		DL	LL	EL
1	LC1	1.5	1.5	-
2	LC2	1.2	1.2	1.2 (X)
3	LC3	1.2	1.2	-1.2 (X)
4	LC4	1.2	1.2	1.2 (Y)
5	LC5	1.2	1.2	-1.2 (Y)
6	LC6	1.5	-	1.5 (X)
7	LC7	1.5	-	-1.5 (X)
8	LC8	1.5	-	1.5 (Y)
9	LC9	1.5	-	-1.5 (Y)
10	LC10	0.9	-	+1.5 (X)
11	LC11	0.9	-	-1.5 (X)
12	LC12	0.9	-	+1.5 (Y)
13	LC13	0.9	-	-1.5 (Y)

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F. Modelling

A G+13 Storey R.C. building was analysed using ETABS Software. The Plan of base and first considered for analysis is shown in Fig. 2 and 3 respectively. The rendered view of a G+13 Storey R.C. building is as shown in Fig. 4.

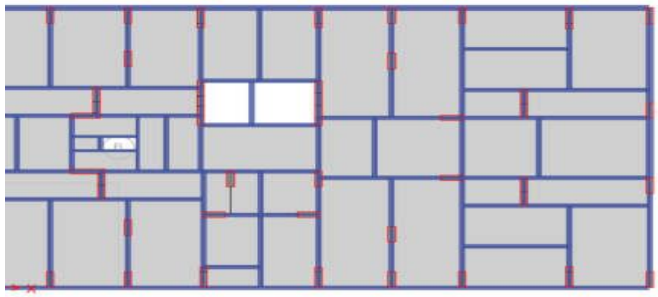

Fig.2 Base (Silt) of the G+13 Building.

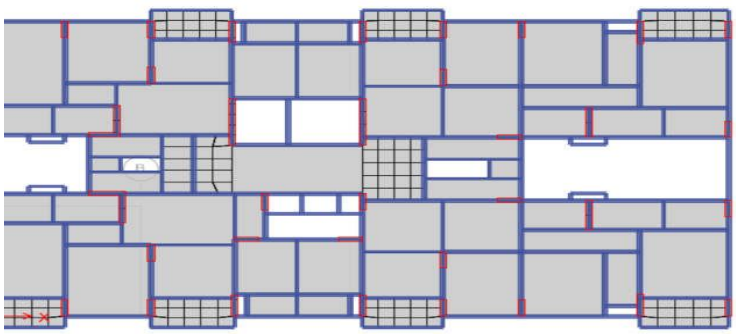

Fig.3 Storey 1 (master storey) of the G+13 Building.

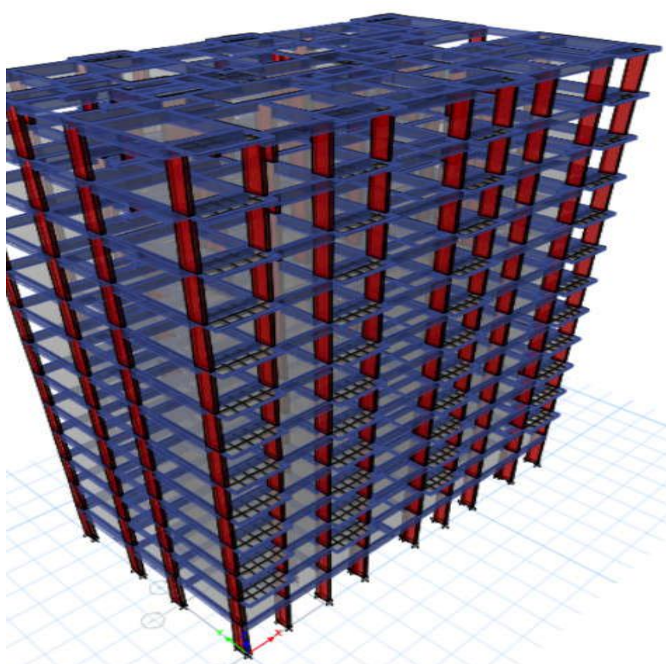

Fig.4 An extruded 3D view of the G+13 Building.

III. RESULTS AND DISCUSSION

The largest expected lateral stress on the structure's base as a result of seismic activity is estimated as base shear. It is calculated using the seismic zone, soil material, and building code lateral force equations. The fundamental period of vibration is used to estimate the base shear of a geodesic dome when subjected to dynamic stresses in this work. For each acceleration data, other results such as joint displacements and frame axial force with respect to time period are collected and used to perform time history analysis of the geodesic dome.

A. Base Shear

The variation of base shear reaction for each time-history load case in the X direction is shown in Fig. 5 to Fig. 10. The vertical axis represents the base shear reaction in kN and the horizontal axis represents ground motion time.

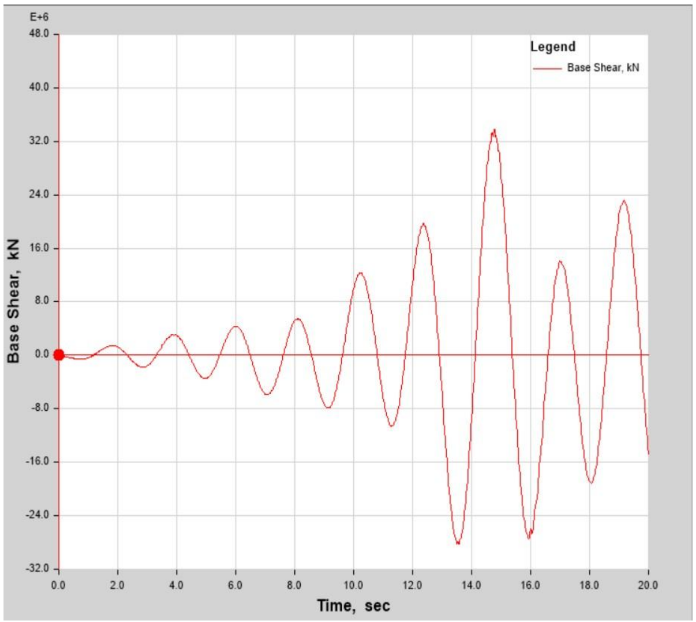

Fig.5 Base shear of G+13 building for El-Centro earthquake ground motion in X direction

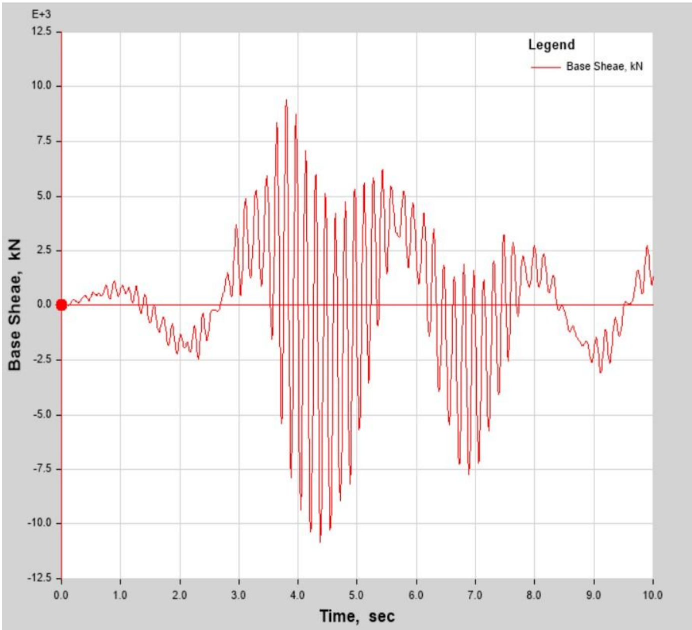

Fig.6 Base shear of G+13 building for Uttarakashi earthquake ground motion in X direction

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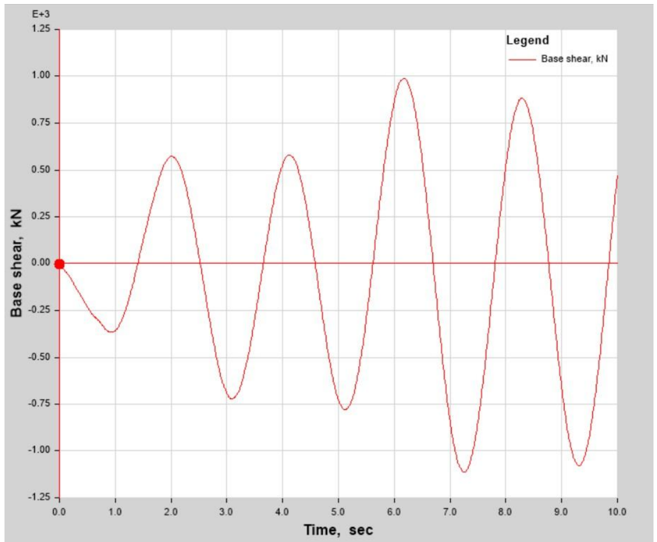

Fig.7 Base shear of G+13 building for Kutch earthquake ground motion in X direction

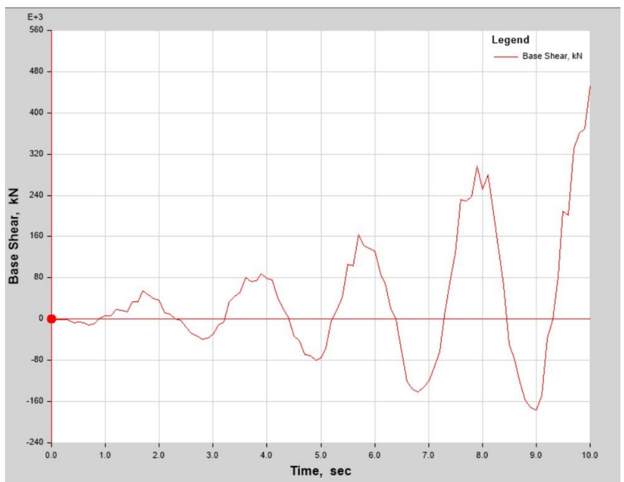

Fig.8 Base shear of G+13 building for Northridge earthquake ground motion in X direction

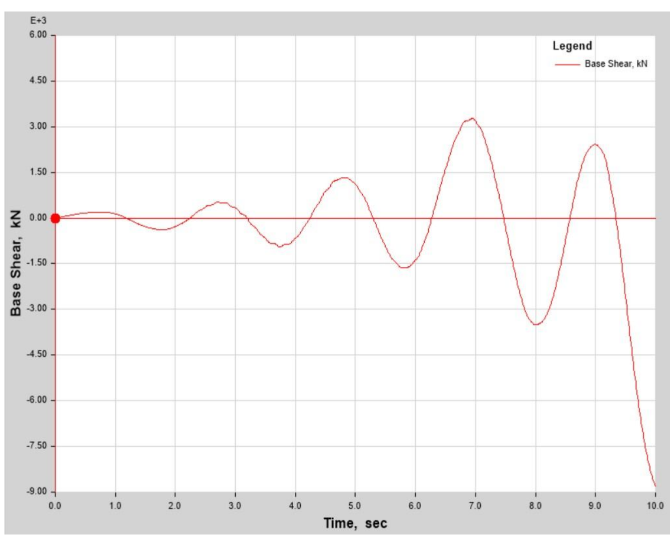

Fig.9 Base shear of G+13 building for Kobe earthquake ground motion in X direction

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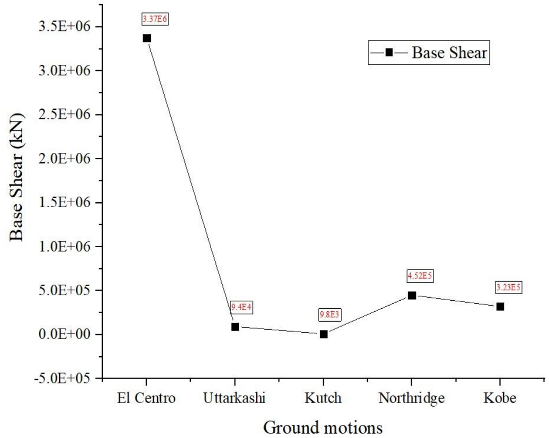

Fig.10 Base Shear comparison on the G+13 building for different ground motions

The results in x- and y -direction are generally similar, which is reasonable as the base shear highly depends on the mass of the building when the ground conditions are equal, and the mass is the same in both directions. For the a El-Centro earthquake, maximum base shear is observed in x direction, and the other ground motion exhibits lower base shear force on the building compared to El-Centro earthquake ground motion. The base shear comparison for the G+13 building for the selected ground motions is shown in Fig.10. El-Centro ground motion exhibits a base shear of 152% higher compared to that of Northridge earthquake ground motion.

B. Joint Displacement

The maximum joint displacement of the G+13 building for different ground motions is shown in Fig. 11. The maximum joint displacement is observed on joint 2481 on the terrace floor of the building.

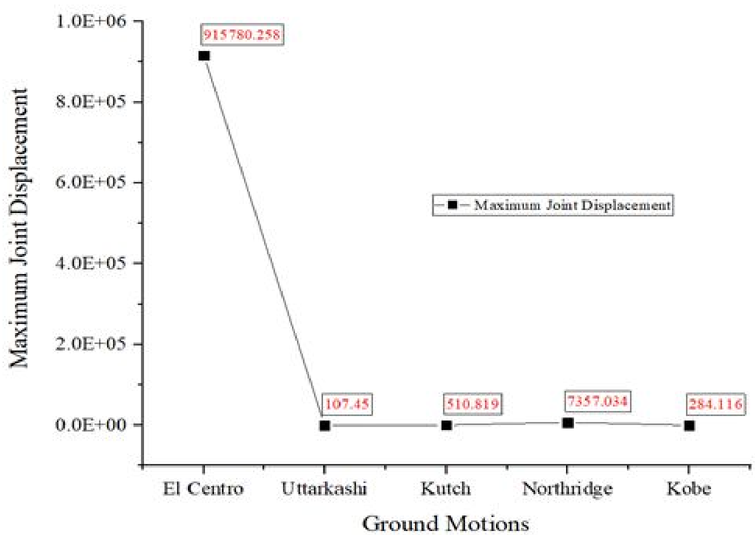

Fig.11 Variation in maximum joint displacement of G+13 building for different ground motions

It is evident from the graph that the El-Centro earthquake ground motion exhibits a maximum joint displacement compared to the other ground motions. However, it is almost 196% higher compared to that of Northridge earthquake ground motion.

IV. CONCLUSIONS

Ground motions causes earthquakes and ground movement has the potential to affect structures. However, understanding the characteristics of ground motion is essential for taking preventative measures against the structural damage that it causes. In this work, the time history response of the G+13 building to various ground motions is investigated. The results like base shear, storey displacement and maximum joint displacements are studied and compared for different earthquake ground motions.

1) Time History is a realistic seismic analysis method that offers a better assurance of the security of structures that have been examined and developed in accordance with IS code.
2) Modal analysis is performed to know the initial and final frequencies which are 0.477 Hz to 5.421 Hz. These frequencies are used to match the ground motion frequency to the building soil and seismic conditions.
3) The residential G+13 building is studied for its behaviour for different ground motions. The base shear found maximum for El-Centro ground motion compared to other ground motions, and its 152% higher compared to base shear of Northridge earthquake ground motion.
4) The joint displacement was maximum at the terrace floor, where the height of the building is essentially affects both storey and joint displacement. The maximum joint displacement observed for El-Centro earthquake ground motions and it is almost 196% higher compared to that of Northridge earthquake ground motion.
5) The structural behaviour of G+13 building is much affected by El-Centro ground motion compared to Indian earthquake motion
6) Kutch earthquake ground motion shows less base shear however, the displacement behaviour of the building was higher. So, it was considered as most severe earthquake in Indian in Damage rate.

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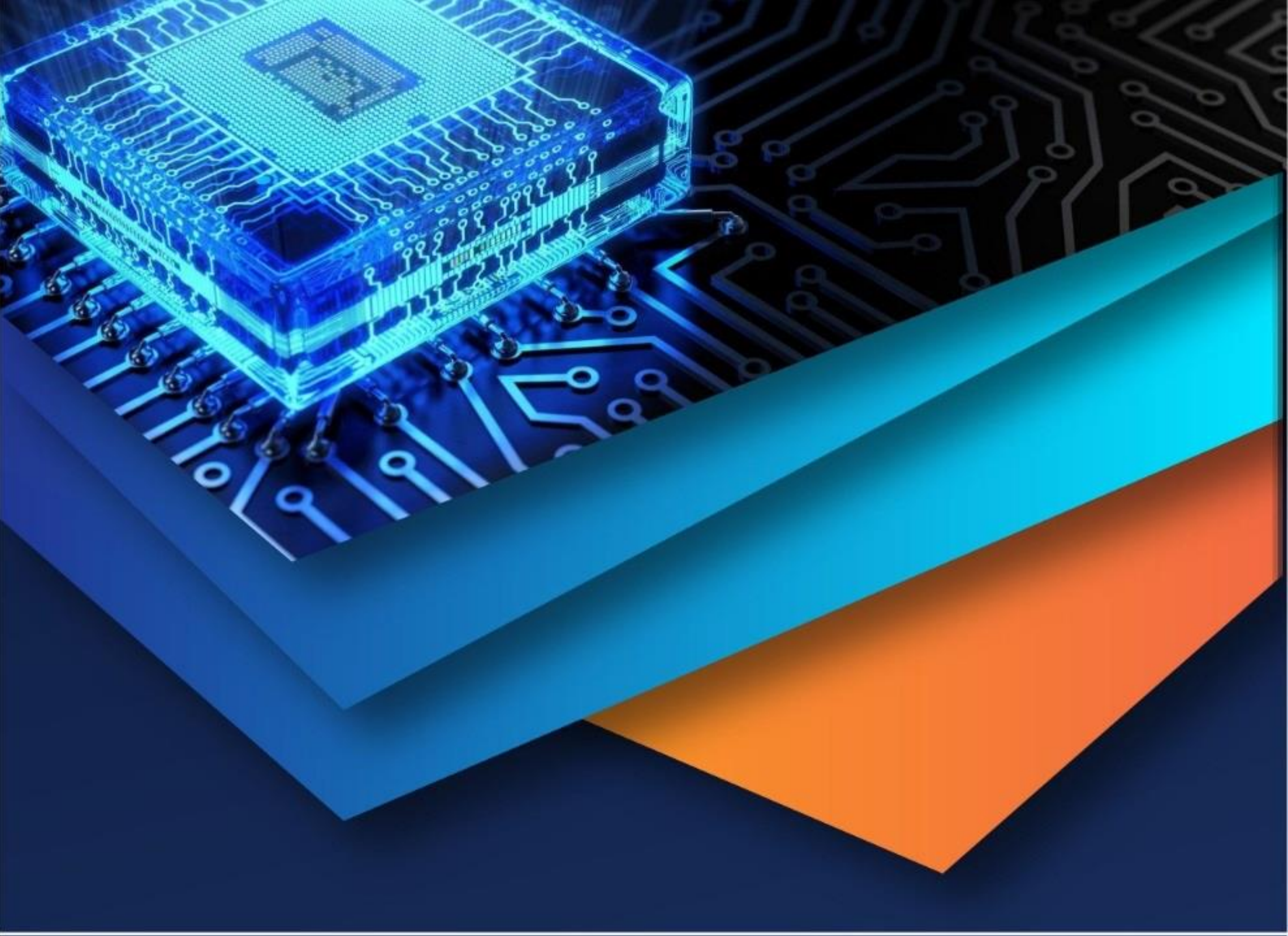

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